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NGC 3312: A VICTIM OF RAM PRESSURE SWEEPING ?

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Introduction

We are undertaking a volume limited survey of the Hydra I cluster in neutral hydrogen using NRAO's Very Large Array (VLA). The main purpose is to study the effects of a dense environment on the gaseous component of the galaxies. Observational evidence has been accumulating recently that ram pressure sweeping does occur in the centers of clusters, but it is possible that tidal interactions play a role as well. In this paper we present results of high resolution H I imaging of NGC 3312, the large peculiar spiral near the cluster center. Hydra I (= A1060) is the nearest rich cluster beyond Virgo and, as such, presents a unique opportunity to do a complete survey of a cluster. It is similar to the Virgo cluster (*e.g.*, Richter 1985) in many of its general physical characteristics, such as, size, X-ray luminosity, velocity dispersion, and galaxy content (high spiral fraction). However, Hydra I appears to be more regular and relaxed. This is evident in the X-ray distribution in its central region, which is radially symmetric and centered on the dominant galaxy, NGC 3311, a cD-like elliptical. The observed X-ray luminosity implies a central gas density of $4.5 \times 10^{-3} \text{ cm}^{-3}$ (Jones and Forman 1984). Gallagher (1978) argued from optical images of NGC 3312 that this galaxy might be an ideal candidate to directly study effects of the ram pressure process; it might currently be undergoing stripping of its interstellar medium. Our data are consistent with this suggestion, but other origins of the peculiar appearance cannot yet be ruled out.

Observations

Forty-eight hours of observations were made at the VLA in both B/C and C/D configurations. The data were on-line Hanning smoothed and calibrated employing standard VLA calibration methods. The UV data from both hybrid arrays were then combined in order to form a high resolution high sensitivity 31 channel data cube. Two maps were created using both natural ($30''7 \times 17''2$ beam) and uniform ($14''2 \times 11''6$ beam) weighting. Line-free channels on either side of the band were combined to form a continuum map which was then subtracted from all channels, leaving a cube of H I emission. The central velocity of this cube is 2850 km s^{-1} and the channel spacing is 41.5 km s^{-1} . We present here the natural-weighted (higher sensitivity) H I images and the uniform-weighted (higher resolution) continuum image. The 3σ -level column density is $5.8 \times 10^{19} \text{ cm}^{-2}$.

Results and Discussion

NGC 3312 is a large peculiar spiral with apparently anemic arms on the west side and dust lanes on the east side. Fig. 1 shows a contour map of the radio continuum emission overlayed on an optical print. The continuum is composed of an unresolved core source of 24 mJy and an extended region associated primarily with the prominent eastern spiral arm(s) of the galaxy. With a cluster radial velocity of 3420 km s^{-1} and a Hubble constant of $50 \text{ km s}^{-1} \text{ Mpc}^{-1}$, this galaxy has a diameter of about 80 kpc. The radio continuum distribution is quite asymmetric. Except for an extension to the northwest (just outside a ridge along several H II regions), the emission is almost completely confined to the dust lanes at the east side of the galaxy. This side is also about 0.3 magnitudes bluer than the mean color of the galaxy as a whole.

The gas distribution is equally asymmetric. Fig. 2 shows the integrated H I emission for NGC 3312 as well as NGC 3314a (south) and a tiny ring galaxy (east). The neutral hydrogen in NGC 3312 is distributed asymmetrically across the disk of the galaxy, with a steep dense ridge on the bluer eastern side and weaker

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emission extending out to the region of the optical filaments noted by Gallagher (1978) in the west. In between lies a central depression. A slice through the center along the minor axis reveals two things: (a) the eastern (left) side rises from less than $6 \times 10^{19} \text{ cm}^{-2}$ to a column density of $1.4 \times 10^{21} \text{ cm}^{-2}$ in less than a beam width (4.3 kpc), while the western (right) side peaks at only $1.1 \times 10^{21} \text{ cm}^{-2}$ and falls off more gradually, and (b) the western side of the galaxy actually contains about 30% more H I than the eastern side. The H I, like the continuum emission, mostly coincides with the regions of active star formation, *e.g.*, no H I is seen coincident with the faint smooth optical extension in the north, which lacks the blue knotty appearance of other northern and eastern features. In general, the distribution of the red light is much more symmetric than that of the H I and radio continuum.

The channel maps and the intensity-weighted mean velocity field (Fig. 3) show that the kinematics are even more irregular than the H I distribution. Especially in the southwest, gas seems to be dragged out and moving at less negative velocities than expected from the underlying rotation pattern. We note here that this is exactly what would be expected from ram pressure sweeping if the galaxy is moving toward us with respect to the mean cluster motion. The changing orientation of the line of nodes in Fig. 3 indicates that this is not simply gas in a disk on circular orbits and it is even more complicated than a warped disk would be. Thus, non-circular motions are indicated in the outer parts.

Even if we take projection effects into account, the observed steep drop in H I surface density inside the optical image in the east is quite unusual. Isolated spiral galaxies usually show H I at higher column densities out to much larger radii than is seen here (*e.g.*, Sancisi 1982). Although sharp edges have been found in a few isolated galaxies, these occur at much larger radii and lower column densities (*e.g.*, Corbelli *et al.* 1989; van Gorkom *et al.* 1989). Although the H I morphology of NGC 3312 is very unusual, it is not unique. A similar morphology (sharp edge on one side and smooth extended H I on the other) has been found in a number of galaxies in the Virgo cluster (Cayatte *et al.* 1989) and in the relatively isolated galaxy NGC 1961 (Shostak *et al.* 1982). For all these examples ram pressure sweeping has been invoked as the most plausible explanation.

We, therefore, suggest that (a) the mechanism responsible for this gas pile-up and deficiency is ram pressure sweeping, and (b) a secondary effect may be enhanced star formation in the pile-up region, indicated by both the continuum distribution and the strong color gradient, and this may cause further gas depletion. A rough calculation of intracluster medium (ICM) densities needed to strip gas down to observed column densities produces values consistent with observations. Assuming NGC 3312 moves through the ICM with a velocity just equal to its radial velocity (-839 km s^{-1} relative to the cluster), and that its mass is uniformly distributed across the disk, the density needed for stripping is $3 \times 10^{-4} \text{ cm}^{-3}$, comfortably below that observed in X-rays.

It is still worthwhile to consider other mechanisms which may be consistent with the observations. Tidal interactions could also produce sharp edges, and an asymmetry in the H I distribution. The interaction could have occurred with the other peculiar spiral in the same field, NGC 3314a. It is located about 7.5 south of NGC 3312 and lies in the same velocity range. An additional reason to suspect an interaction between these two is that both exhibit tails of neutral hydrogen, indicative of tidal interaction. NGC 3314a has a long tail of emission pointing away from NGC 3312, while NGC 3312 has a short arm pointing toward NGC 3314a. Thus the tails are close to parallel; the momentum vectors of the galaxies are parallel as well. The alignment of the tails is not easily understood in a tidal interaction scenario, while it would be the most likely orientation if the two galaxies are moving together through an ICM and are being stripped.

There is also a finite chance that NGC 3312 along with the other galaxies detected (NGC 3314a, Ring, etc.) form a genuine foreground group. In this case, one might compare this "group" with the NGC 1961 group (Shostak *et al.* 1982). Since the X-ray emission is centered on NGC 3311, we must then conclude that no ICM of significance is present in the group, and the peculiar morphology of NGC 3312 must be due to a tidal interaction. Simulations are required to test this hypothesis. A bonus of the foreground hypothesis is that it would explain why these galaxies seem brighter and bigger than most Hydra I galaxies.

Given the study on cluster substructure by Fitchett and Merritt (1988) and keeping in mind that Hydra I is isolated in redshift space, the group hypothesis is perhaps plausible. However, a more likely interpretation is then, that the entire group is currently falling into Hydra I, thus it would be a background and not a foreground group. In such a situation the H I observations are pointing to ram pressure sweeping again. As mentioned above, the roughly parallel extensions of both NGC 3312 and NGC 3314a seem to favor this interpretation. Note, however, that in this scenario we can derive a lower limit for the transverse velocity

of NGC 3312 which is more than five times the radial velocity dispersion of the potential "group" members. This is done via a dynamic interpretation of the optical appearance of the eastern side of NGC 3312. Dust on the front side seems to absorb light from part of the bulge. Thus, it must have been moved – by ram pressure – above the disk. For this to happen, NGC 3312 must move into the ambient medium with some inclination with respect to edge-on. The inclination on the sky is about 72° therefore the transverse velocity must be at least 280 km s^{-1} ($= v_r \cdot \cot i$ with $v_r = -839 \text{ km s}^{-1}$). This seems unlikely and either a genuine foreground group with tidal interactions or genuine cluster members undergoing ram pressure sweeping (and, possibly, simultaneous tidal interactions) remain the plausible alternatives.

Conclusions

The results can be summarized as follows:

- A steep, smooth edge on the east side of the galaxy, seen in optical (B), radio continuum, and neutral hydrogen is consistent with NGC 3312 having its outer regions of gas stripped and its leading edge gas compressed as it moves through the cluster.
- The continuum distribution and new UBVR photometry indicate that recent star formation has occurred in the "piled-up" gas, which may have also contributed to the gas depletion.
- If it is being stripped, the proper motion of NGC 3312 can be inferred to be at least 280 km s^{-1} in a northeastern direction. This motion through the intracluster gas has moved the H I in the leading side out of the original disk.
- Gallagher (1978) proposed ram pressure sweeping to explain NGC 3312 based on faint filaments extending from the back side of the galaxy seen in the optical.

Although we cannot exclude the possibility that NGC 3312 and NGC 3314a are tidally interacting in a foreground group, we suggest, based on the above evidence, that NGC 3312 is, indeed, an ideal candidate to study the detailed effects of ram pressure sweeping.

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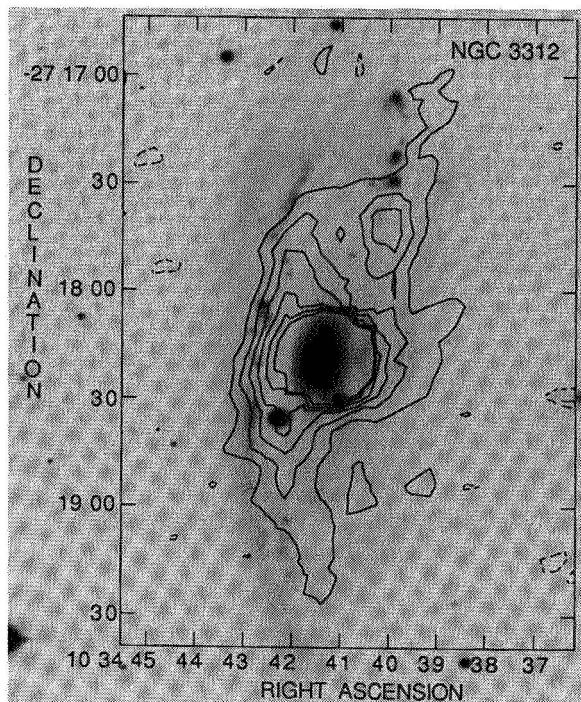


Fig. 1 Overlay of the radio continuum radiation at 21cm from NGC 3312 on an optical photograph taken by A. Sandage at the Las Campanas DuPont 2.5m telescope. Contour levels are -2, 2, 4, 6, 8, 10, and 12 σ , where $\sigma = 0.2$ mJy/Bm.

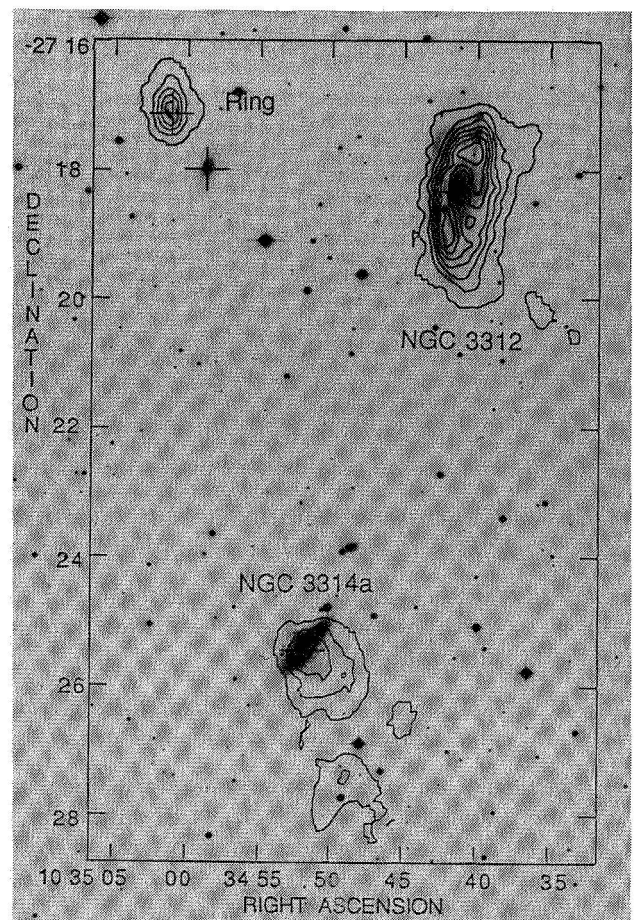


Fig. 2 Integrated H I distribution of NGC 3312, NGC 3314a, and the Ring galaxy overlaid on the optical photograph. The contour levels are in steps of $7 \times 10^{19} \text{ cm}^{-2}$ beginning at 10^{19} cm^{-2} .

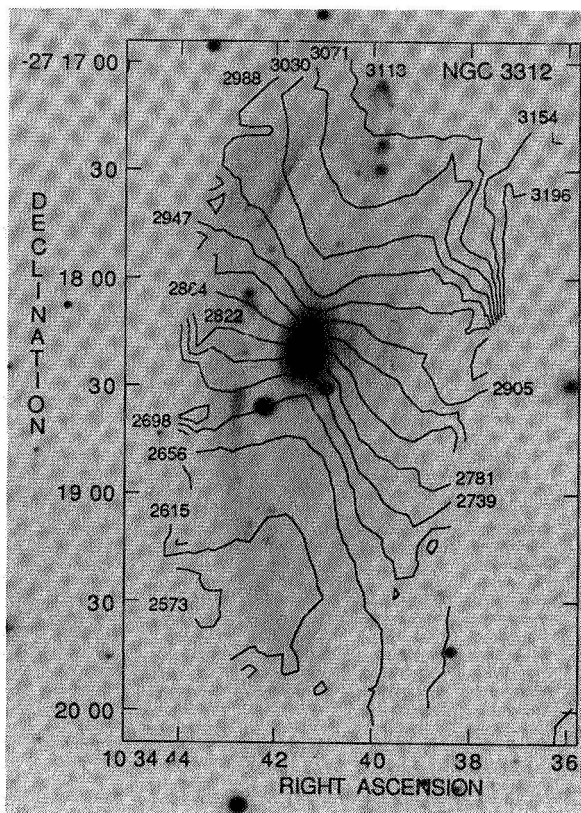


Fig. 3 The velocity field of NGC 3312. Note the strong asymmetry and the bent line of nodes. Velocities are in units of km/s.